electro optical industries, inc.

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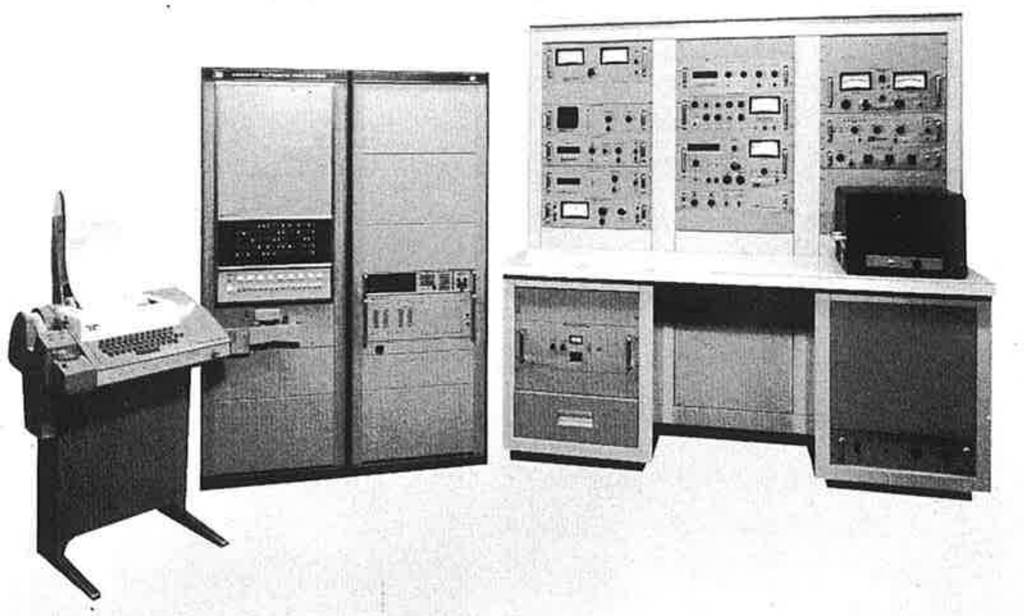
Interim Manual Blackbody Radiation Sliderule*



*This is a temporary manual and will be replaced shortly with a two color typeset manual.

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BLACKBODY RADIATION SLIDERULE

Explanation of Scales

Planck's expression for spectral radiant flux density into a surrounding hemisphere in the wavelength interval λ to $\lambda + d\lambda$ is

$$H\lambda = \frac{2\pi hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1} \quad [W/cm^2 - \mu m]$$

The corresponding expression for spectral radiant photon density

$$Q\lambda = \frac{2\pi c}{\lambda^4} \frac{1}{e^{hc/\lambda kT} - 1} \quad [photons/sec - cm^2 - \mu m]$$

where* $c = 2.997925 \times 10^{10}$ cm/sec

$h = 6.6256 \times 10^{-34}$ Joule - sec

$k = 1.38054 \times 10^{-23}$ Joule / deg k

t_f, t_c, T

The three temperature scales, t_f, t_c, and T give blackbody temperature in degrees Fahrenheit, Centigrade, and Kelvin, respectively.

λ_1 λ_2

The wavelength scales, λ_1 and λ_2, give wavelength in the intervals

$$.3 \leq \lambda_1 \leq 30\ \mu m$$
$$30 \leq \lambda_2 \leq 3000\ \mu m$$

on the ENERGY side of the rule, and

$$.35 \leq \lambda_1 \leq 40\ \mu m$$
$$40 \leq \lambda_2 \leq 4000\ \mu m$$

on the PHOTONS side.

* NBS Misc. Publ. 253, Revised May, 1969

v_1, v_2

The wavenumber scales give wavenumbers in the intervals

$$320 \leq v_1 \leq 40000 \quad cm^{-1}$$
$$3.2 \leq v_2 \leq 400 \quad cm^{-1}$$

on the ENERGY side, and

$$250 \leq v_1 \leq 30000 \quad cm^{-1}$$

$$2.5 \leq v_2 \leq 300 \quad cm^{-1}$$

on the PHOTONS side.

$H_{o-\infty}$, $Q_{o-\infty}$

The $H_{o-\infty}$ scale gives the value of

$$H_{o-\infty} = \int_0^\infty H_\lambda \, d\lambda = \frac{2\pi^5 k^4}{15 h^3 c^2} T^4 \qquad [W/cm^2]$$

the total power radiated by unit area of a blackbody at temperature T.

The analogous photons scale, $Q_{o-\infty}$, gives

$$Q_{o-\infty} = \int_0^\infty Q_\lambda \, d\lambda = \frac{4\pi k^3}{h^3 c^2} (1.202057) T^3 \qquad [photons / sec - cm^2]$$

the total number of photons emitted by unit area of a blackbody at temperature T.

$H_{\lambda m}$, $Q_{\lambda m}$

The $H_{\lambda m}$ scale gives the maximum value of the function H_λ at a given value of T,

$$H_{\lambda m} = \frac{2\pi k^5}{h^4 c^3} (21.201436) T^5 \qquad [W/cm^2 - \mu m]$$

with

$$Q_{\lambda m} = \frac{2 \pi k^4}{h^4 c^3} (4.77984) \quad T^4 \qquad \left[\text{photons / sec-cm}^2 - \mu\text{m}\right]$$

the analogous maximum of the function Q_λ.

$H_{\lambda 1} / H_{\lambda m}$, $H_{\lambda 2} / H_{\lambda m}$ $Q_{\lambda 1} / Q_{\lambda m}$, $Q_{\lambda 2} / Q_{\lambda m}$

These scales give the value of the indicated ratios for wavelengths read on either the λ_1 or λ_2 scales. They are

$$\frac{H_{\lambda 1}}{H_{\lambda m}} = \frac{\left(\frac{hc}{\lambda_1 kT}\right)^5}{e^{hc/\lambda_1 kT} - 1} \quad \frac{1}{21.201436} \qquad \frac{H_{\lambda 2}}{H_{\lambda m}} = \frac{\left(\frac{hc}{\lambda_2 kT}\right)^5}{e^{hc/\lambda_2 kT} - 1} \quad \frac{1}{21.201436}$$

$$\frac{Q_{\lambda 1}}{Q_{\lambda m}} = \frac{\left(\frac{hc}{\lambda_1 kT}\right)^4}{e^{hc/\lambda_1 kT} - 1} \cdot \frac{1}{4.77984082} \qquad Q_{\lambda 2} = \frac{\left(\frac{hc}{\lambda_2 kT}\right)^4}{e^{hc/\lambda_2 kT} - 1} \quad \frac{1}{21.201436}$$

(dimensionless)

$$\frac{H_{o - \lambda_1}}{H_{o - \infty}}, \quad \frac{Q_{o - \lambda_1}}{Q_{o - \infty}}, \quad \frac{H_{\lambda 2 - \infty}}{H_{o - \infty}}, \quad \frac{Q_{\lambda 2 - \infty}}{Q_{o - \infty}}$$

These scales give the fraction of blackbody power (or photon rate) emittance falling in the indicated wavelength interval. For wavelengths read from the λ_1 scale, the ratios are

$$\frac{H_{o - \lambda_1}}{H_{o - \infty}} = \frac{\int_0^{\lambda_1} H_\lambda \, d\lambda}{\int_0^{\infty} H_\lambda \, d\lambda} = \frac{15}{\pi^4} \sum_{n=1}^{\infty} \frac{e^{-nu}}{n^4} (n^3 u^3 + 3n^2 u^2 + 6 nu +$$

$$\frac{Q_{o-\lambda_1}}{Q_{o-\infty}} = \frac{\int_0^{\lambda_1} Q_\lambda \, d\lambda}{\int_0^{\infty} Q_\lambda \, d\lambda} = \frac{1}{2.404117} \sum_{n=1}^{\infty} \frac{e^{-nu}}{n^3} \left(n^2 u^2 + 2nu + 2 \right)$$

where $u \equiv \dfrac{hc}{\lambda k T}$. (dimensionless)

For convenience, the other integrated quantities are taken from λ_2 to ∞ :

$$\frac{H_{\lambda 2 - \infty}}{H_{o-\infty}} = \frac{\int_{\lambda_2}^{\infty} H_\lambda \, d\lambda}{\int_0^{\infty} H_\lambda \, d\lambda} = 1 - \frac{\int_0^{\lambda_2} H_\lambda \, d\lambda}{\int_0^{\infty} H_\lambda \, d\lambda}$$

$$\frac{Q_{\lambda 2 - \infty}}{Q_{o-\infty}} = \frac{\int_{\lambda_2}^{\infty} Q_\lambda \, d\lambda}{\int_0^{\infty} Q_\lambda \, d\lambda} = 1 - \frac{\int_0^{\lambda_2} Q_\lambda \, d\lambda}{\int_0^{\infty} Q_\lambda \, d\lambda}$$

(dimensionles

$V_n / \sqrt{R \Delta f}$

This scale gives RMS Johnson noise potential per root ohm-hertz,

$$\frac{V_n}{\sqrt{R \Delta f}} = \sqrt{4kT} \qquad V/\sqrt{hz-\Omega}$$

$E_{\lambda m}$

This scale gives the energy of a photon having wavelength λm (at the maximum of H_λ) emitted at temperature T.

$$E_{\lambda m} = (4.965114)\, kT \qquad \text{ev}$$

Problem-solving with the radiation sliderule **

The Stock Scales

Quantities which are functions of T alone, $H_{o-\infty}$, $Q_{o-\infty}$, λ_m, $H_{\lambda m}$, $Q_{\lambda m}$, $V_n / \sqrt{R \Delta f}$, $E_{\lambda m}$, can be read directly from the appropriate stock scales, when the hairline is set to the desired temperature.

EXAMPLE: Set the hairline to 1000^{o} K on the **T** scale. Read directly beneath it

$$H_{o-\infty} = 5.7 \text{ w / cm}^2$$

$$H_{\lambda m} = 1.3 \text{ w / cm}^2 - \mu\text{m}$$

$$V_n / \sqrt{R \Delta f} = 2.34 \times 10^{-10} \text{ V / } \sqrt{\text{hz-}\Omega}$$

$\lambda_m = 2.9\ \mu\text{m}$ on the λ_1 scale

from the ENERGY side of the stock, and the photon quantities

$$Q_{o-\infty} = 1.52 \times 10^{20} \text{ photons/ sec - cm}^2$$

$$Q_{\lambda m} = 2.1 \times 10^{19} \text{ photons/ sec-cm}^2 - \mu\text{m}$$

$$E_{\lambda m} = .427 \text{ ev}$$

$\lambda_m = 3.67\ \mu\text{m}$ on the λ_1 scale

from the PHOTONS side of the stock.

** Powers of ten are denoted in Feynman notation on this rule; e.g., 4 E - 8 is equal to 4×10^{-8}.

The Slide Scales

Quantities which are functions of both wavelength and temperature, $H_{\lambda 1}/H_{\lambda m}$, $H_{\lambda 2}/H_{\lambda m}$, $Q_{\lambda 1}/Q_{\lambda m}$, $Q_{\lambda 2}/Q_{\lambda m}$, $H_{o-\lambda 1}/H_{o-\infty}$, $H_{\lambda 2-\infty}/H_{o-\infty}$, $Q_{o-\lambda 1}/Q_{o-\infty}$, $Q_{\lambda 2-\infty}/Q_{o-\infty}$ can be read from the appropriate slide scale when the central TEMPERATURE arrow on the slide is placed below the desired temperature, and the hairline is placed over the desired wavelength on the λ_1 or λ_2 scale.

EXAMPLE: Move the slide until the TEMPERATURE arrow is directly below $1000^{o}K$ on the T scale. Set the hairline over 2 μm on the λ_1 (ENERGY side) scale, and read beneath it

$$H_{\lambda 1}/H_{\lambda m} = .68$$

$$H_{o-\lambda 1}/H_{o-\infty} = 6.7 \times 10^{-2}$$

for a blackbody at the given wavelength and temperature.

Turn the rule over to the PHOTONS side, reset the hairline to 2 μm on the λ_1 scale, and read beneath it

$$Q_{\lambda 1}/Q_{\lambda m} = .42$$

$$Q_{o-\lambda 1}/Q_{o-\infty} = 2.1 \times 10^{-2} .$$

Computing Absolute Bandpass Quantities

It is possible to compute various absolute quantities for a given wavelength interval by means of the relations

$$H_{\lambda 1} = \left(\frac{H_{\lambda 1}}{H_{\lambda m}}\right) \cdot H_{\lambda} \qquad H_{\lambda 2} = \left(\frac{H_{\lambda 2}}{H_{\lambda m}}\right) \cdot H_{\lambda m}$$

$$Q_{\lambda 1} = \left(\frac{Q_{\lambda 1}}{Q_{\lambda m}}\right) \cdot Q_{\lambda m} \qquad Q_{\lambda 2} = \left(\frac{Q_{\lambda 2}}{Q_{\lambda m}}\right) \cdot Q_{\lambda m}$$

and

$$\int_{\lambda a}^{\lambda b} H_\lambda \, d\lambda = \left(\frac{H_{o-\lambda b}}{H_{o-\infty}} - \frac{H_{o-\lambda a}}{H_{o-\infty}} \right) \cdot H_{o-\infty}$$

$$\int_{\lambda a}^{\lambda b} Q_\lambda \, d_\lambda = \left(\frac{Q_{o-\lambda b}}{Q_{o-\infty}} - \frac{Q_{o-\lambda a}}{Q_{o-\infty}} \right) \cdot Q_{o-\infty}$$

for long wavelength intervals. The differential forms

$$H_\lambda \, \Delta\lambda$$

$$Q_\lambda \, \Delta\lambda$$

may be used for small wavelength intervals. The four multiplier scales, $M(H_{\lambda m})$, $M(H_{o-\infty})$, $M(Q_{\lambda m}$, $M(Q_{o-\infty})$ have been included to expedite the required multiplications.

EXAMPLE: Compute the value of H_λ associated with temperature $T = 1500^oC$ and wavelength $\lambda = 8.5\ \mu m$.

Move the slide until the TEMPERATURE arrow is directly beneath 1500^oC on the t_c scale. Then set the hairline over $8.5\ \mu m$ on the λ_1 scale and read the value of $H_\lambda / H_{\lambda m}$, 2.4×10^{-2}, directly beneath it on the $H\lambda_1 / H_{\lambda m}$ scale. Transfer this value to the $M(H_{\lambda m})$ multiplier scale by resetting the hairline, and read

$$H_\lambda = .54 \quad W/cm^2 - \mu m$$

beneath it on the $H_{\lambda m}$ scale.

EXAMPLE: Compute $H_{o-\lambda}$ for a temperature of 350^oF and wavelength of $20\ \mu m$.

First compute the value of

$$\frac{H_{o-\lambda}}{H_{o-\infty}} = .89$$

as before. Transfer this value to the $M(H_{o-\infty})$ scale by resetting the hairline; read beneath it

$$H_{o-\lambda_1} = .21 \quad W/cm^2$$

on the $H_{o-\infty}$ scale.

Extending the range of a scale

The stock scales may be used with higher or lower values of temperature than those represented on the rule. Simply multiply the desired (absolute) temperature by 10 raised to a convenient power, so that the new temperature appears on the T scale. Solve the problem using this new value of T, then multiply the result by the appropriate factor as listed in Table 1.

Table 1

If T is multiplied by	multiply the value of	by a factor of
10^{-n}	$H_{o-\infty}$	10^{4n}
10^{-n}	$Q_{o-\infty}$	10^{3n}
10^{-n}	$H_{\lambda m}$	10^{5n}
10^{-n}	$Q_{\lambda m}$	10^{4n}
10^{-n}	$Vn/\sqrt{R \Delta f}$	$10^{n/2}$
10^{-n}	$E_{\lambda m}$	10^{n}

NOTE: Without recourse to Table 1, it is possible to deduce the required factor by inspection of the scale itself. For example, if T is reduced by a factor of ten in going from $1000^\circ K$ to $100^\circ K$, say the value of $Q_{o-\infty}$ evidently decreases by a factor of 10^3 1.52×10^{20} to 1.52×10^{17}. Thus, an additional ten-fold temperature reduction to $10^\circ K$ would give $Q_{o-\infty} = 1.52 \times 10^{14}$ photons/sec. cm^2.

A similar extension procedure can be used with each of the stock scales.

EXAMPLE: Find $Q_{o-\infty}$ for a blackbody at temperature $T = 20{,}000^\circ K$. Using the $Q_{o-\infty}$ scale, solve the problem for $T=2{,}000^\circ K$ $(20{,}000^\circ K \times 10^{-1})$. The result is 1.22×10^{21} photons/sec. cm^2. Now multiply this number by a factor of $10^{3n} = 10^3$ to give

$$Q_{o-\infty} = 1.22 \times 10^{24} \text{ photons/sec. cm}^2$$

The slide scales can also be used over an extended range of temperature and wavelength. Select new, convenient values of λ and T such that the product λT is the same as for the original problem. The result obtained in this way will be correct without modification.

EXAMPLE: Find $H_\lambda / H_{\lambda m}$ for T-15000°K and $\lambda = .25\ \mu$ m.

Here, the product λT will be unchanged if the problem is solved for T = 1500°k and $\lambda = 2.5\ \mu$ m. Using the $H_{\lambda 1} / H_{\lambda m}$ and T scales, the result is

$$\frac{H\lambda}{H\lambda m} = .86$$

for the desired temperature and wavelength.

NOTE: If absolute quantities are subsequently to be derived by means of the slide multiplier scales, it is necessary to modify the results obtained according to Table 1.

Sample Problems (cf. appendix for more detailed solutions)

How much radiant power is emitted by a 1.0 square cm. piece of firebrick at 1000°C? The total emissivity of firebrick at this temperature is .75.

Solution:
$$\begin{aligned} P &= H_{0-\infty} \\ &= (.75)\,(15)\ \mathrm{W/cm^2} \\ &= 11\ \mathrm{W/cm^2} \end{aligned}$$

using the t_c, $H_{0-\infty}$ and $M(H_{0-\infty})$ scales.

What is the RMS Johnson noise potential developed across a 10,000 Ω resistor at a temperature of 175°F in a 1-hz bandwidth?

Solution:
$$Vn = \left(\frac{Vn}{\sqrt{R\,\Delta f}}\right) \cdot \sqrt{R\,\Delta f} \quad \text{for } 175^\circ F$$

$$Vn = 1.39 \times 10^{-10}\ \frac{V}{\sqrt{hz - \Omega}} \cdot \sqrt{10{,}000\ \Omega \cdot 1\ hz}$$

$$= 1.39 \times 10^{-8}\ V$$

using the t_f and $Vn/\sqrt{R\,\Delta f}$ scales.

How much radiant power is emitted by 1.0 sq. cm of a tungsten rod at temperature $2800^{\circ}K$ in the wavelength interval $.7 \leq \lambda \leq .75\ \mu m$? The emissivity of tungsten in this interval is .42.

<u>Solution:</u>

$$\Delta H = \epsilon \int_{\lambda a}^{\lambda b} H_\lambda \, d\lambda \quad \text{for } T = 2800^{\circ}K$$

$$= (.42) \int_{.7}^{.75\mu m} H_\lambda \, d\lambda$$

$$= .42 \left\{ \int_{0}^{.75\mu m} H_\lambda \, d\lambda - \int_{0}^{.7\mu m} H_\lambda \, d\lambda \right\}$$

$$= .42 \left(\frac{H_{o-.75\ \mu m}}{H_{o-\infty}} - \frac{H_{o-.7\ \mu m}}{H_{o-\infty}} \right) . H_{o-\infty}$$

$$= .42\ (.083 - .060)\ .\ H_{o-\infty}$$

$$= .42\ (.023)\ H_{o-\infty}$$

$$= (.42)\ 8.0\ W$$

$$= 3.4\ W$$

using the T, λ_1, $H_{o-\lambda 1} / H_{o-\infty}$, $M(H_{o-\infty})$, $H_{o-\infty}$, C and D scales.

What is the photon count from a 1.0 cm^2 blackbody at $3000^{\circ}C$ in the interval $15,000 \leq v \leq 25,000\ cm^{-1}$?

<u>Solution:</u>

$$\Delta Q = \int_{v=25,000}^{v=15,000\ cm^{-1}} Q_\lambda \, d\lambda \quad \text{at } 3000^{\circ}C$$

$$= \left(\frac{Q_{o-15000\ cm^{-1}}}{Q_{o-\infty}} - \frac{Q_{o-25000\ cm^{-1}}}{Q_{o-\infty}} \right) . Q_{o-\infty}$$

$$= (.033 - .001)\ .\ Q_{o-\infty}$$

$$= .032\ Q_{o-\infty}$$

$$= 1.7 \times 10^{20} \text{ photons/sec}$$

using the t_c, v_1, $Q_{o-\lambda_1} / Q_{o-\infty}$, $M(Q_{o-\infty})$ and $Q_{o-\infty}$ scales.

How much total radiant power is emitted by a 1.0 square cm. blackbody at temperature $T = 45^{\circ}K$?

Solution: $H = H_{0-\infty}$

$= .23 \times 10^{-4}$ W

$= 2.3 \times 10^{-5}$ W

using the T and $H_{0-\infty}$ scales with Table 1.

Find the total radiant power emitted by a $6000^{\circ}K$ blackbody in a 100 Å band width around .35 μ m

Solution: $\Delta H = H_{\lambda} \; \Delta\lambda$

$= \left(\frac{H_{\lambda}}{H_{\lambda m}}\right) \cdot H_{\lambda m} \; \Delta\lambda$

$= .75 \; H_{\lambda m} \; \Delta\lambda$

$= 7.5 \times 10^{3} \; W/cm^{2} \text{-}\mu m \times 100 \times 10^{-4} \; \mu m$

$= 75 \; W/cm^{2}$

using the T, λ_1, $H_{\lambda 1} / H_{\lambda m}$, M ($H_{\lambda m}$) and $H_{\lambda m}$ scales.

How much radiant power is received from a 4.0 cm^2 blackbody source at $2700^{\circ}K$ if the blackbody is directly in front of the receiver, 100 cm away?

Solution: $H = \frac{S_b}{\pi d^2} \qquad H_{0-\infty}$

where d = distance between viewer and source ; S_b = radiating blackbody ar

$$H = \frac{4.0 \; cm^2 \times 3.0 \times 10^2 \; W/cm^2}{3.14 \times (100)^2 \; cm^2}$$

$$H - 3.8 \times 10^{-2} \; W/cm^2_{\text{receiver}}$$

using the T, $H_{0-\infty}$, C and D scales.

APPENDIX

Sample Problem 1: Set the hairline to $1000^{o}C$ on the t_c scale, and read the value 15 W/cm^2 on the $H_{o-\infty}$ scale. To multiply this number by the emissivity, .75, the $M(H_{o-\infty})$ multiplier scale may be used: move the slide until the TEMPERATURE arrow is on $1000^{o}C$. Then set the hairline over .75 on the $M(H_{o-\infty})$ scale, and read the required result, 11 W/cm^2, on the $H_{o-\infty}$ scale.

Sample Problem 2: Set the hairline to the temperature, $175^{o}F$ on the t_f scale. Read the value of $Vn/\sqrt{R\,\Delta f}$, 1.39×10^{-10} $V/\sqrt{hz\text{-}\Omega}$, and multiply this by the value of

$$\sqrt{R\,\Delta f} = \sqrt{10{,}000\ \Omega \cdot 1\ hz} = 100\sqrt{hz\text{-}\Omega}$$

The result if $Vn = 1.39 \times 10^{-8}$ V. For more difficult numberical values, the square root may be found using the T and D scales: the D scale will read-out directly the square root of the number under the hairline on the T scale. Multiplication can then be carried out with the C and D scales.

Sample Problem 3: Set the TEMPERATURE arrow to $2800^{o}K$ on the T scale, and move the hairline to .75 μm on the λ_1 scale. Read the value of $H_{o-\lambda 1}/H_{o-\infty}$, .083. Now, move the hairline to .7 μ m and read the value of $H_{o-\lambda 1}/H_{o-\infty}$ for this wavelength .060. The difference of these two values, .083 - .060 = .023 must be multiplied by $H_{o-\infty}$; set the hairline over .023 on the $M(H_{o-\infty})$ scale and read the value 8.0 W from the $H_{o-\infty}$ scale. Now use the C and D scales to multiply this number by .42, the emissivity. The result is 3.4 W.

Sample Problem 4: Move the TEMPERATURE arrow to read $3000^{o}C$ on the t_c scale, and set the hairline over 15,000 cm^{-1} on the V_1 scale. Read the value of $Q_{o-\lambda 1}/Q_{o-\infty}$, .033. Reset the hairline to 25,000cm^{-1} and read the value of $Q_{o-\lambda 1}/Q_{o-\infty}$ for this frequency, .001. Compute the difference of these two values, .033-.001= .032 and set the hairline to this number on the $M(Q_{o-\infty})$ scale. Read the required result, 1.7×10^{20} photons/sec, from the $Q_{o-\infty}$ scale.

Sample Problem 5: Since the temperature of interest, $45^\circ K$, is below the range of the T scale, multiply it by 10^1 and set the hairline to the new temperature, $450^\circ K$, on the **T** scale. Read the value .23W on the $H_{0-\infty}$ scale. Since the value of T was multiplied by $10^{-n} = 10^1$, n = -1 here, and the value .23W must be multiplied by a factor of $10^{4n} = 10^{-4}$ to give the correct result for $T = 45^\circ K$. It is

$$
\begin{aligned}
H_{0-\infty} &= .23 \times 10^{-4} \text{ W} \\
&= 2.3 \times 10^{-5} \text{ W.}
\end{aligned}
$$

Sample Problem 6: For this small wavelength interval, the differential form

$$\int_{\lambda a}^{\lambda b} H_\lambda \, d\lambda = H_\lambda (\lambda b - \lambda a) = H_\lambda \Delta \lambda$$

is used. Set the TEMPERATURE ARROW to $6000^\circ K$ on the T scale. Set the hairline to .35 μm on the λ_1 scale, and read the value of $H_{\lambda 1} / H_{\lambda m}$, .75 . Reset the hairline to this number on the M ($H_{\lambda m}$) scale, then read the value of $H_\lambda = 7.5 \times 10^3$ W/cm^2-μ from the $H_{\lambda m}$ scale. Multiply this number by $\Delta\lambda = 100 \text{ Å} = 100 \times 10^{-4}$ μ m. The result is $\Delta H = 75$ W/cm^2.

Sample Problem 7: Set the hairline to $2700^\circ K$ on the T scale, and read beneath it the value of $H_{0-\infty}$, 3.0×10^2 W/cm^2. Now use the C and D scales to multiply this number by

$$\frac{S_b}{\pi d^2} = \frac{4.0 \text{ cm}^2}{3.14 \times (100)^2 \text{ cm}^2}$$

The result is $H = 3.8 \times 10^{-2}$ W/cm^2 receiver.

References:

H. W. Makowski, "A Slide Rule for Radiation Calculations," Review of Scientific Instruments, 20, 876 (1949)

M. Pivovonsky and M. R. Nagel, Tables of Blackbody Radiation Functions, Macmillan Co., N. Y. (1961)

HOW TO ADJUST YOUR SLIDERULE

Each rule is accurately adjusted before it leaves the factory. However, handling during shipment, dropping the rule, or a series of jars may loosen the adjusting screws and throw the scales out of alignment. Follow these simple directions for slide rule adjustment.

ALIGNMENT OF RULE BODY

1. Position your slide rule so that the adjusting screws in the two end-plates are up and away from you.

2. Loosen the two end-plate screws to achieve slight flexibility in the rule

3. Position the slider (or center part of the rule so that its left index is aligned with the index on the fixed stator (at the bottom of the rule).

4. Keeping the slider aligned, position the movable stator (at the top of the rule) so that its index is aligned with the slider.

5. With the thumb and forefinger, apply slight pressure to the left side of the rule, and tighten the screw. (Leave a small gap between the slider and stators to achieve smooth rule movement: approximately .003".)

6. Apply slight pressure to the right side of the rule and tighten that adjusting screw - again leaving a small gap.

7. Confirm alignment on the reverse side of the rule.

ALIGNMENT OF WINDOW ASSEMBLY

1. Loosen all screws on both sides of the window assembly to make the assembly flexible.

2. Working on one side of the rule, locate the unsprung cursor bar; e.g., the bar that does not have a tension spring. (Cursor bars are the opaque teflon components that ride on the edge of the rule.)

3. Using thumb and forefinger, apply upward pressure to the bottom of the unsprung bar - so that it rests firmly against the rule's edge.

4. Also position the window so that the hairline is perpendicular to the index lines on the left side of the rule. Tighten the screw(s) in the unsprung bar. Leave the other Screw(s) loose.

5. Turn the rule over and repeat the preceding steps:

a. Apply pressure against the cursor bar which has no spring.
b. Make certain the hairline is perpendicular to the left index
c. Tighten the screw(s) in the unsprung bar.

6. Continuing on the same side of the rule, tighten the screw(s) in the cursor bar, which is spring-loaded.

7. Reverse the rule and tighten the remaining screw(s) in the spring-loaded bar.

8. Move the window to the opposite end of the rule to confirm alignment with the righthand index.

REPLACEABLE ADJUSTING SCREWS

HOW TO KEEP YOUR SLIDE RULE IN CONDITION

Operation

Always hold your rule between thumb and forefinger at the ends of the rule. This will insure free, smooth movement of the slider. Holding your rule at the center tends to bind the slider and hinder its free movement.

Cleaning

Wash surface of the rule with a non-abrasive soap and water when cleaning the scales.

Lubrication

The metal edges of your slide rule will require lubrication fom time to time. To lubricate, put a little white petroleum jelly (Vaseline) on the edges and move the slider back and forth several times. Wipe off any excess lubricant. Do not use ordinary oil as it may eventually discolor rule surface.